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Evaluation of Bearing Plates Installed on Full-Column Resin-Grouted Bolts

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UNITED STATES DEPARTMENT OF THE INTERIOR

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CONTENTS

	Page
Abstract	1
Introduction	2
Acknowledgments	2
General considerations	2
Instrumentation	4
Field investigation--Roadside Mine	6
Field investigation--Bear No. 3 Mine	8
Conclusions	12
References	12

ILLUSTRATIONS

1.	Approximate location of the Roadside and Bear No. 3 Mines	3
2.	Generalized stratigraphic column of the Roadside Mine	3
3.	Generalized stratigraphic column of the Bear No. 3 Mine	4
4.	Compression pad diagram	4
5.	Hydraulic U-cell plates and bladder	5
6.	Vertical displacement gauge	6
7.	Roadside Mine test site location	6
8.	Roadside Mine load contours 3 days and 72 days after test site installation	7
9.	Roof spalling in Roadside Mine test site	8
10.	Final Roadside Mine load contours 205 days after test site installation	9
11.	Bear No. 3 Mine test site location	9
12.	Instrumentation layout in the Bear No. 3 Mine	10
13.	Bear No. 3 Mine load and roof displacement contours 128 days and 301 days after test site installation	11

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	in	inch
ft^2	square foot	lb	pound
ft·lbf	foot-pound (force)	psi	pound per square inch

EVALUATION OF BEARING PLATES INSTALLED ON FULL-COLUMN RESIN-GROUTED BOLTS

By Stephen C. Tadolini[1] and Bryan F. Ulrich[1]

ABSTRACT

The Bureau of Mines conducted field investigations in two underground mines to determine the actual loads to which bearing plates were subjected when installed in conjunction with full-column resin-grouted bolts and the roof movements generated by the applied loads. Measured loads indicate that the bearing plate is an integral part of the support system. Vertical displacement gauges installed to monitor roof displacements in the test sites show that the highest degrees of loading occur in conjunction with the largest amounts of movement.

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INTRODUCTION

Resin bolting systems continue to gain popularity in underground mines throughout the United States, and their general success under a wide range of geological and operational conditions is well documented. However, many questions dealing with basic support mechanisms and the influence of various factors on effectiveness in situ remain only partly answered. The Bureau of Mines conducted a major research project to investigate the usefulness of bearing plates installed at the bottom (collar) of a full-column, resin-grouted bolt.

The use of full-column, resin-grouted bolts to stabilize underground mine roofs necessitates the ability to determine support characteristics and behavioral patterns. These investigations have taken two forms in recent research. The first form involves investigating support systems and individual bolts by an exact theoretical solution, or modeling. These methods analyze the state of stress in and around the bolts in three phases. The first phase analyzes the initial loading of the bolt-grout-rock. The second phase considers subsequent movements along the bolt and in the immediate area. The third and final phase involves the analysis of discontinuous rock movements along normal bedding planes. The results from these types of investigations generally conclude that the load transfer mechanism in grouted bolts dictates that all movements, and thus generated loads, are controlled along the bolt axis and interbed slips. This implies that the bearing plates' effectiveness is limited to helping retain loose material at the mine roof (1-3).[2]

The second form of solution involves field investigations designed to analyze actual phenomena witnessed in underground mines. Bearing plates and, consequently, bolts appear to be subjected to large amounts of load, which cause plates to bend, bolts to elongate, and bolt ends to fail completely. When bearing plates at the head of a full-column, untensioned, properly installed grouted bolt are subjected to significant loads, they can be considered to be contributing to the support of the mine roof. Therefore, the assumption has been made that load on the bearing plate indicates that the plate may be an important part of the support system. To verify this assumption, full-column resin-grouted bolts were installed in coal mine roofs equipped with devices to measure the load applied during installation and subsequent roof loading carried by the bearing plates. To determine if the loads are related to the underground stability, roof deflection measurements were recorded. The loads were then compared with roof movements to determine if a correlation exists between the two parameters.

ACKNOWLEDGMENTS

The authors would like to thank the mine operators and all who contributed to the success of this effort. Special thanks are given to Jim Diamanti, mine manager, Powderhorn Coal Co., and to Bill Bear, president, Bear Coal Co., for their continued support and the use of their personnel and equipment in this study.

GENERAL CONSIDERATIONS

The study includes field test results from two mines: the Roadside Mine and the Bear No. 3 Mine (fig. 1). Both test sites were chosen because of thick coal seams in which the mines are located and the geological characteristics of the rock above the coal seam. The first phase of this investigation was conducted in the Roadside Mine, owned and operated by the Powderhorn Coal Co. The Roadside Mine is located in the Book Cliffs Coalfield of the Uinta coal region. The

[2] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

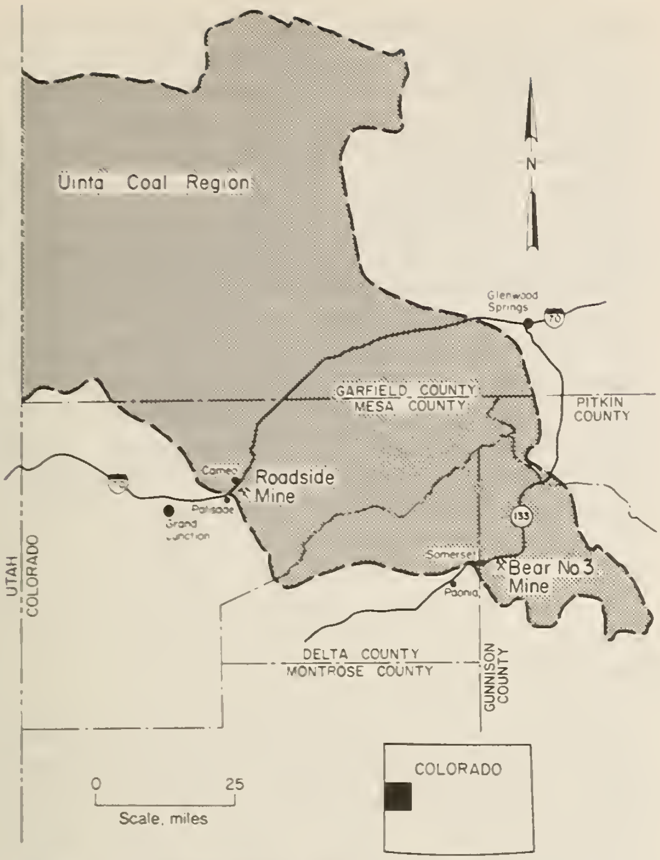

FIGURE 1.-Approximate location of the Roadside and Bear No. 3 Mines.

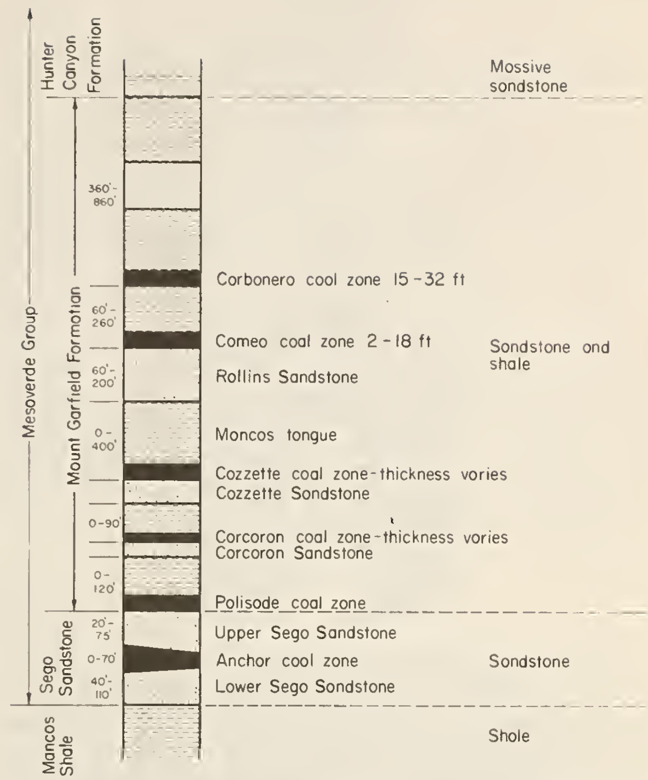

FIGURE 2.-Generalized stratigraphic column of the Roadside Mine.

geology consists of interfingering sandstones and shales of Upper Cretaceous age with several important coal zones. Bedding generally dips about 5° northeast away from the Uncompaghre Uplift toward the southwest rim of the Piceance Creek Basin. A generalized stratigraphic column of the Roadside Mine area is shown in figure 2.

The oldest exposed rock unit in the area is the Mancos Shale, a black to dark-gray soft shale with occasional thin sandstone beds. The Mancos grades upward into the Sego Sandstone, a fine-grained, buff to light-gray sandstone with some gray shale. The Sego is divided into an upper and lower member by the Anchor coal zone, a tongue of the Mancos Shale, which has been mined in some parts of the area.

The Mount Garfield Formation consists of buff and gray, medium-fine-grained sandstone interbedded with gray shale. There are five economically important coal zones in the area. The Palisade zone forms the base of the Mount Garfield Formation. The Corcoran coal zone and the Cozzette coal zone overlie the Corcoran and Cozzette Sandstone Members, respectively. The Cameo coal zone overlies the Rollins Sandstone Member. This zone produces most of the coal from the Book Cliffs Coalfield. The Roadside Mine produces from the Cameo B seam, which is 4.4 to 9.4 ft thick. The uppermost coal zone is the Carbonera.

The uppermost unit in the area is the Hunter Canyon Formation. The Hunter Canyon is a medium-coarse-grained, buff and gray, massive cliff-forming sandstone with small beds of gray to greenish-gray shale. There are no coal deposits in this formation (4-5).

The second phase of the investigation was performed in the Bear No. 3 Mine, owned and operated by the Bear Coal Co. The mine is located in the Somerset coalfield near Somerset, CO. The oldest exposed rock unit in the Somerset area is the Upper Cretaceous Mancos Shale (fig. 3). This unit consists of 2,000 to 3,000

ft of black or dark-gray soft shale with the thin sandstone beds. Overlying Mancos is the Mesaverde Formation, also of Upper Cretaceous age, here composed of four members. The basal member, the Rollins Sandstone, is a 150- to 200-ft-thick, massive, cliff-forming, white to light-yellow-brown sandstone. The lower coal (Bowie Shale) member is an interbedded and lenticular sandstone, siltstone, and shale sequence 250 to 300 ft thick; it contains three important coal seams. The A seam forms the base of the member and is 0 to 5 ft thick. The B seam was mined previously directly below the Bear No. 3 Mine in the Edwards Mine. The C seam, 7 to 9 ft thick, is the seam presently being mined. The seams are all separated by 33 to 40 ft.

The upper coal (Paonia Shale) member is lithologically very similar to the lower coal member but is more lenticular. Up to 400 ft thick in some areas, this contains two major coal seams, the D and E seams. A similar but non-coal-bearing member, the Barren Member, overlies the upper coal member, bringing the entire mine cover to approximately 1,000 ft.

There are numerous igneous intrusives of post-Eocene age throughout the area, some of which appear in mine. The coalbeds dip north and northeast at 0° to 6°. Faults and other fractures occur throughout the area with stratigraphic displacements of 2 to 20 ft (6).

INSTRUMENTATION

Several types of instrumentation were used in this investigation to measure plate loading and roof movements. Compression pads and hydraulic U-cells were used to directly measure the loads applied to bearing plates after bolt installation. Vertical displacement gauges were installed to measure differential roof displacements during test site monitoring and support operations. In addition, observation holes were drilled throughout the test areas to monitor with a stratascope the locations and widths of roof separations.

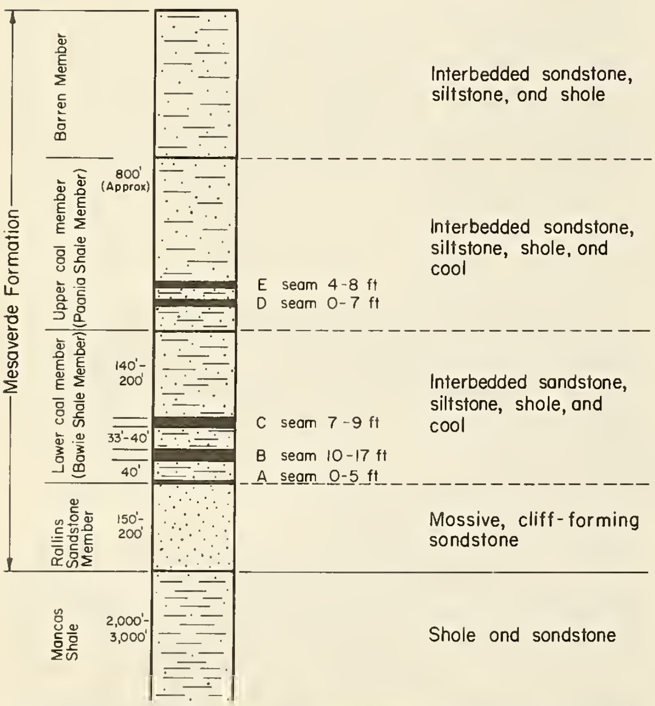

FIGURE 3.-Generalized stratigraphic column of the Bear No. 3 Mine.

Each compression pad (fig. 4) consists of a rubber membrane placed between two steel plates. The compression pads have a working load limit of 32,000 lb with a calculated accuracy of ±200 lb. Readings of the compression pads are monitored with a special calibrated ring that measures the change in circumference of the rubber membrane as it loads and unloads. Laboratory tests on the ring indicate that when loads exceed 30,000 lb, the accuracy drops to ±1000 lb. The

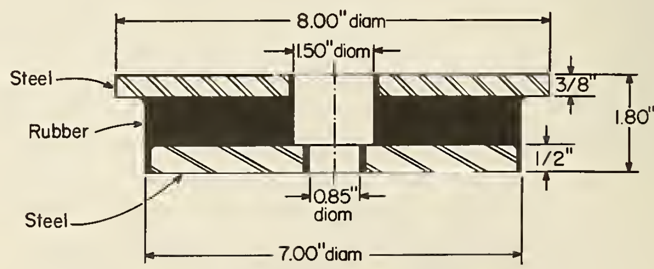

FIGURE 4.-Compression pad diagram.

nature of the pad is to act as a spring between the bolthead and the roof. In laboratory investigations the pad, after being subjected to high loads, failed to rebound to its specified unloaded circumference. The rubber tends to permanently deform after continued loading. In this investigation only positive loading was recorded, eliminating the possibility of inaccurate readings.

The hydraulic U-cells are U-shaped, fluid-filled, flatjack-type load cells used to measure relative loads between the bearing plate and the installed roof bolt (fig. 5). The cell and accompanying platens are designed to fit "horseshoe" fashion about the bolthead for easy installation and retrieval. Each U-cell was individually calibrated in a stiff testing machine to allow the measurement of cell pressure. The U-cells can measure loads to 30,000 lb with measured accuracies of ±250 lb. Resin bolt applications required that the bolthead be threaded to facilitate installation and removal.

The vertical-displacement gauge (fig. 6) consists of four spring clips used to anchor high-strength, stainless steel prestretched wire at selected depths in a 1-3/8-in-diam hole drilled in the mine roof. The uppermost spring clip is placed in a stable layer to be used as a base reference for measured displacements. For this investigation, a hole depth of 7 ft was used. The remaining three spring clips are placed at 5 ft, 3 ft, and 1 ft away from the bolthead. The wires from the four spring clips run through a 10-in-long tube anchored in the collar of the drill hole. The wires go through numbered holes in the copper cap on the end of the tube and have small brass fittings that are used as reference points. A loop is made at the end of the wires so that a 3-lb weight can be attached to maintain a constant tension on the wire while readings are taken. Readings are made with a dial indicator placed between the cap and the reference point on each wire.

The bearing plates used in the investigation were laboratory tested. The ASTM standard requires that the plate be preloaded to 6,000 ft·lbf when measuring displacements, to within 0.001 in, of the axial movement of the bolthead. The load is then increased to 15,000 ft·lbf, and the axial displacement is read. The maximum permissible deflection between the 6,000- and 15,000-ft·lbf loads is 0.120

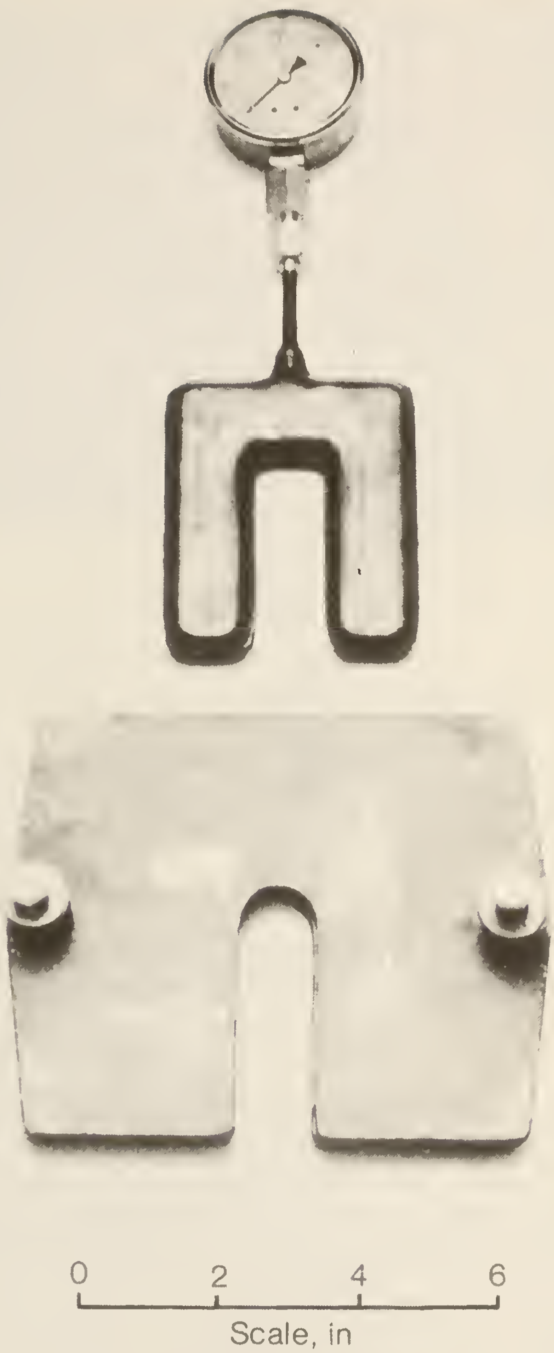

FIGURE 5.-Hydraulic U-cell plates and bladder.

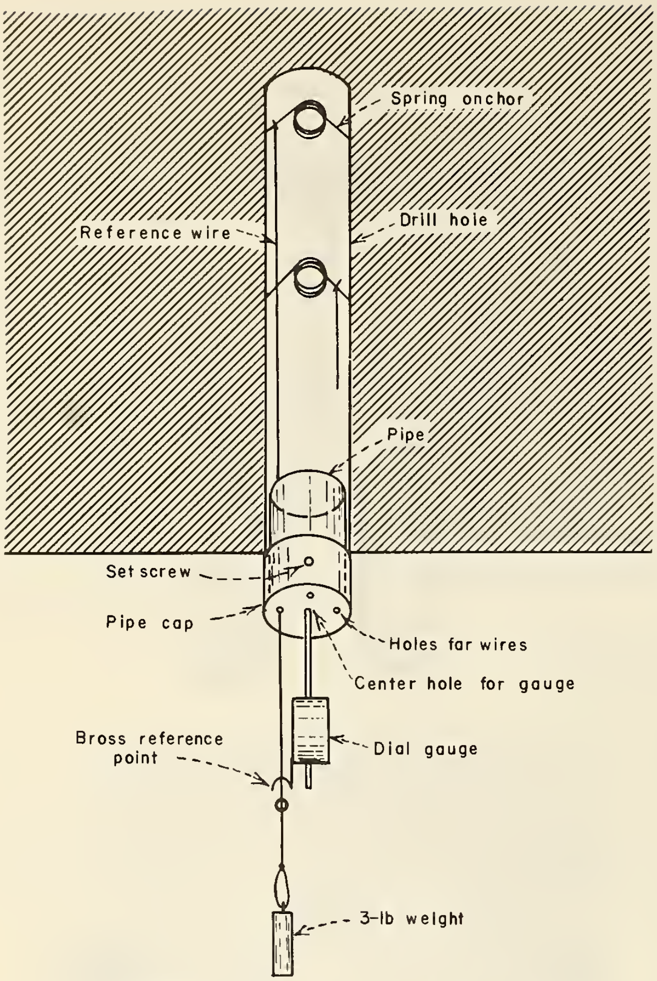

FIGURE 6.-Vertical displacement gauge.

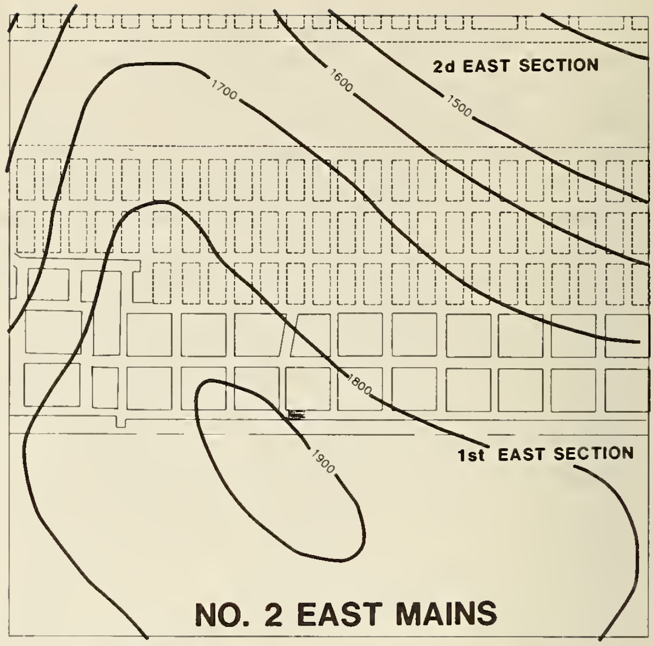

FIGURE 7.-Roadside Mine test site location.

in. The plate is then loaded to 20,000 ft•lbf, and again the axial displacement is measured. The maximum permissible deflection between the 6,000- and 20,000-ft•lbf loads is 0.250 in (7).

Six bearing plates were randomly selected and tested from a purchased lot of 250. All plates exceeded the ASTM standards by a minimum of 15%.

FIELD INVESTIGATION--ROADSIDE MINE

The first phase of this investigation was conducted in the Roadside Mine. The test site was established in a development panel in the No. 2 East Mains, 1st East section in one of the deepest areas of the mine (fig. 7). The test site instrumentation was located approximately midway in an 80-ft room and included 44 compression pads and 6 vertical displacement gauges. This combination of instrumentation made possible the measurement of both the loads on the bearing plates and the separations in the immediate roof. The test site instrumentation was read and evaluated four times in a 7-month period.

Bolts used in these test sites were standard 0.75-in-diam reinforcing-steel-rod-type, grade 40 (17,600-lb yield strength and 30,000-lb tensile strength) roof bolts. The bolts were installed in 1.0-in-diam holes to the specifications of the resin manufacturer. The bolt characteristics varied from bolt to bolt in some cases; all bolt characteristics are the minimum documented laboratory values.

Three days after the excavation of the opening and the installation of the instrumentation, a distinguishable loading pattern was observed (fig. 8). The minimum and maximum loads measured on the bearing plates were 5,700 lb and 29,000 lb, respectively; the average load on the bearing plates in the test area was approximately 14,000 lb. The high concentration of loads in the middle third of the entry caused the laminated shale roof to separate and fall when not confined by the wire mats installed in

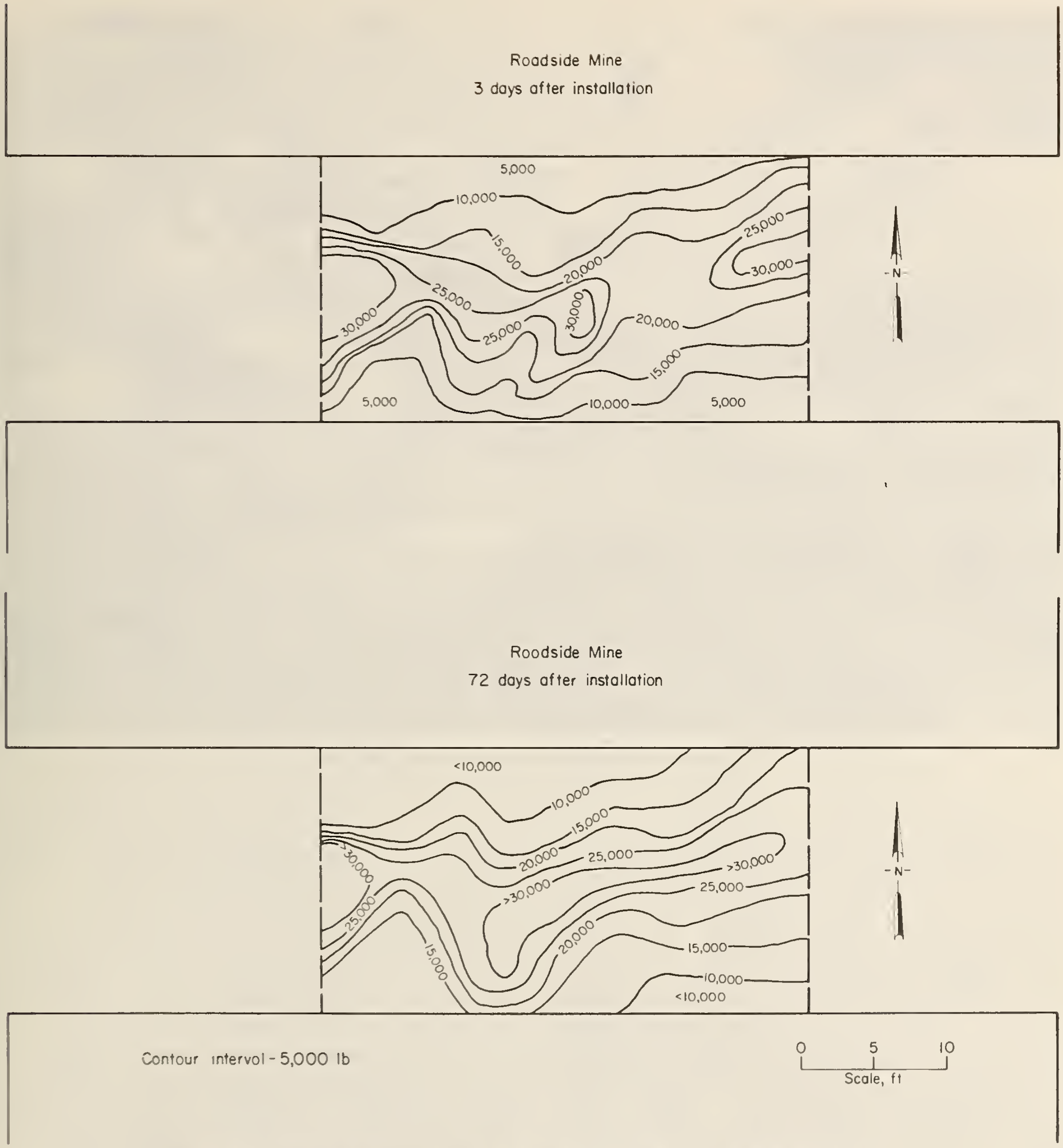

FIGURE 8.-Roadside Mine load contours 3 days and 72 days after test site installation.

conjunction with the bolts. The differential sag stations were lost owing to their roof deterioration.

The loading trends observed 72 days after installation were similar to those recorded at 3 days; however, the loads increased by 30% (fig. 9). Loads on the bearing plates ranged from 6,100 lb to 32,000 lb and averaged 18,100 lb. Visual examination of the test area revealed high degrees of roof spalling, as shown in figure 9.

The measurements recorded 150 days after installation were similar to the 72-day measurements. The minimum and maximum loads were 7,400 lb and 32,000

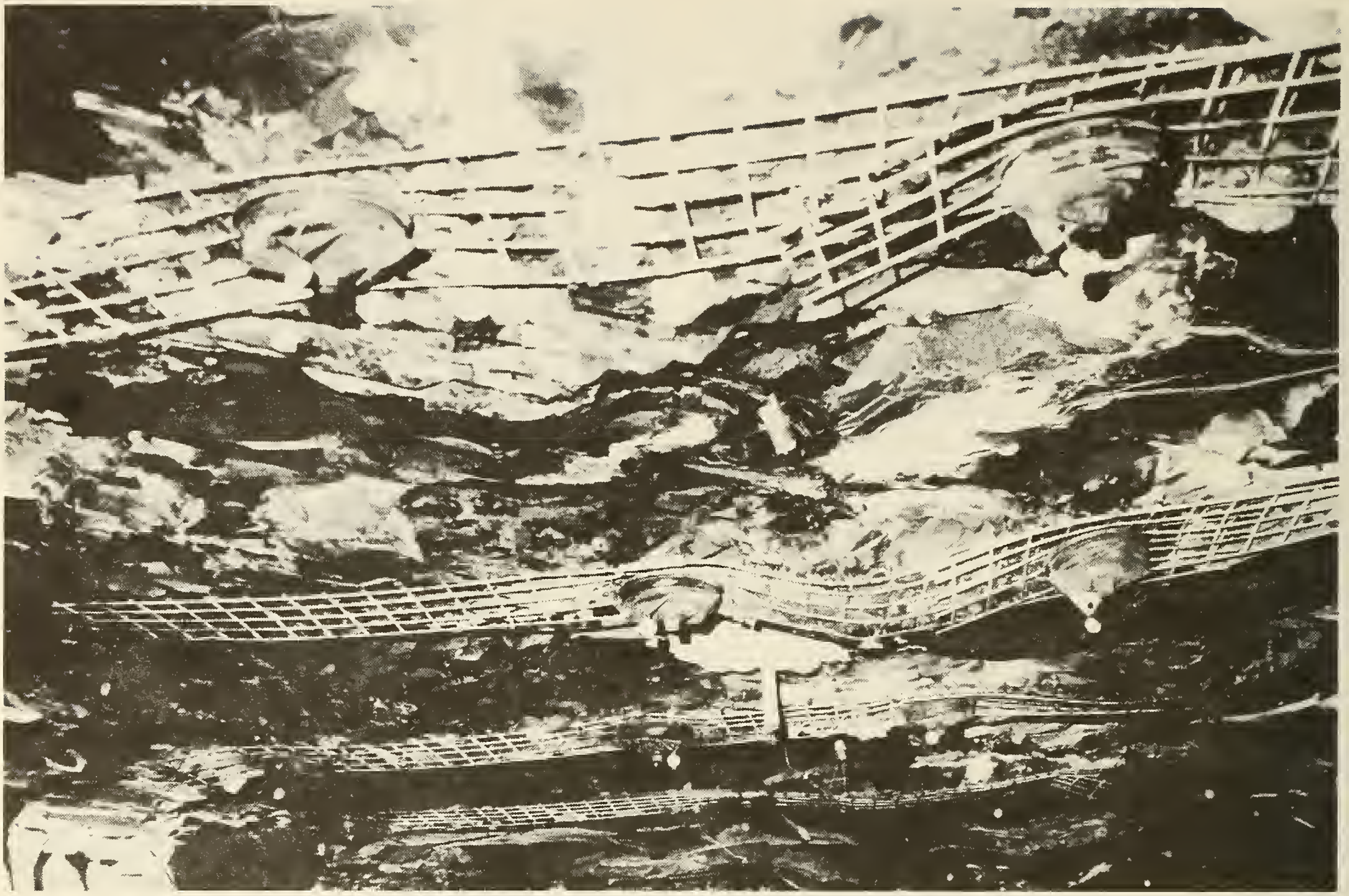

FIGURE 9.-Roof spalling in Roadside Mine test site.

lb, respectively. The average load on the 44 pressure pads was 18,300 lb, or 475 psi. These loads generated up to 41,000 psi of axial stress on the 3/4-in bolts, causing them to yield.

The final measurements were recorded 205 days after the test site was established. At that time, panel development was complete and the pillar retreat line was approaching the test site (approximately 300 ft away inby). The pillars were yielding, by design, resulting in high load concentrations that propagated toward the test site area. As the pillars adjacent to the test site yielded, the loss of rib coal to sloughing resulted in an increase of effective roof span to approximately 30 ft. Figure 10 shows the final loading pattern. The maximum and minimum loads were 7,500 lb and 32,000 lb. The average load, measured on the bearing plates, was 18,900 lb. These test results showed, unconditionally, that bearing plates were subjected to high degrees of loading and were an important part of the total support system. However, because all the vertical displacement gauges were lost and the borescope holes were closed, the roof displacements generated by these loads remained unknown.

FIELD INVESTIGATION--BEAR NO. 3 MINE

The second phase of the investigation was performed in the Bear No. 3 Mine. The test site was located in an entry, including both a three-way and a four-way intersection, under approximately 600 ft of overburden (fig. 11). A total of 5,600 ft^2 of roof was instrumented to monitor bearing plate loads and roof

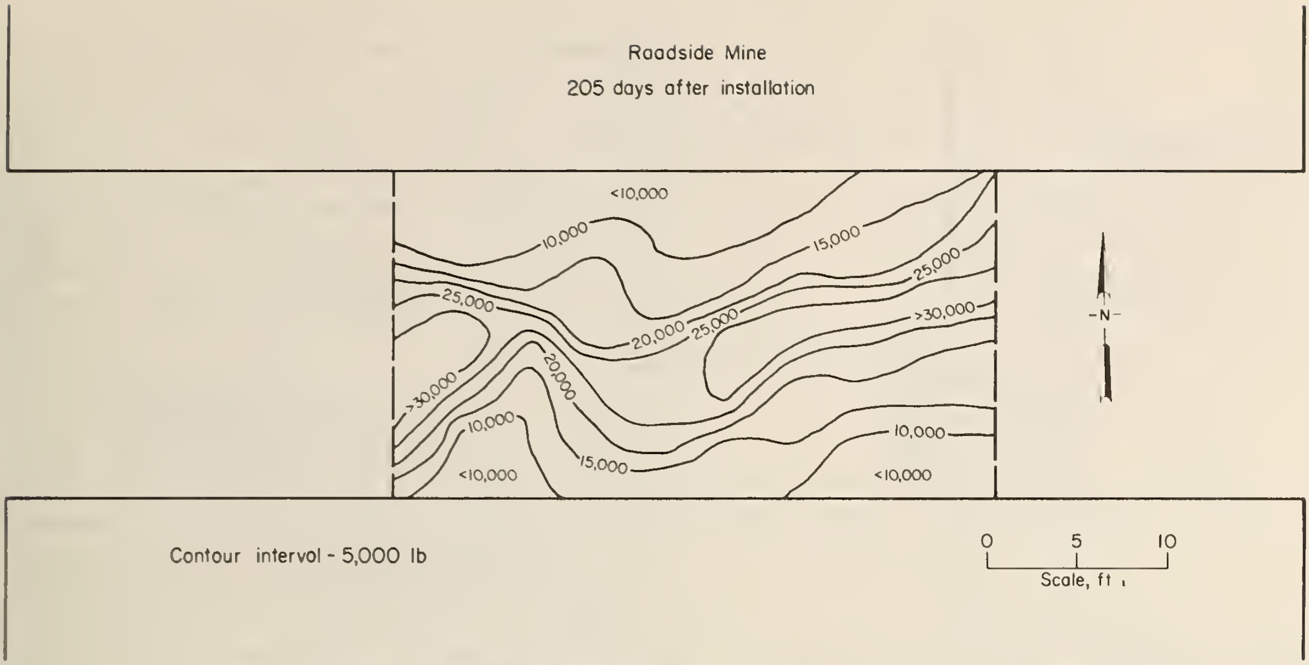

FIGURE 10.-Final Roadside Mine load contours 205 days after test site installation.

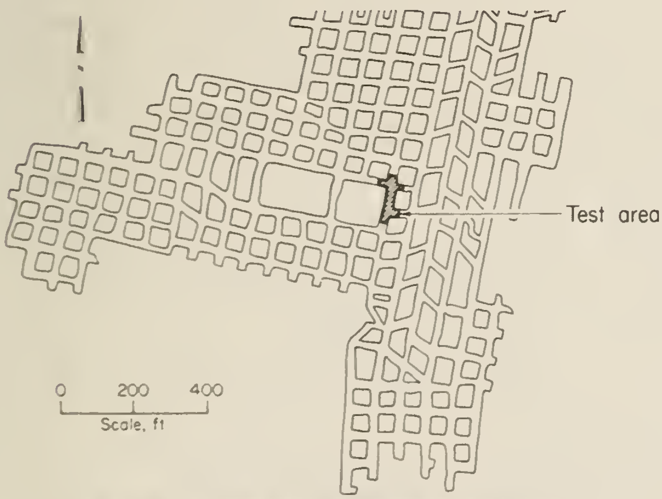

FIGURE 11.-Bear No. 3 Mine test site location.

displacements. To measure the loads on the bearing plates, 51 compression pads and 26 hydraulic U-cells were placed between the mine roof and the bearing plates. Additionally, 14 vertical displacement sag station gauges and 7 fiber-optic boreholes were installed to monitor roof movements (fig. 12). The test site instrumentation was read and evaluated seven times in a 10-month period.

After the test site was instrumented, on traditional 20-ft mining cycles, the baseline data were recorded. The total site was instrumented in 7 days.

The pillars showed no signs of yielding or sloughing. However, a high-angle, clay-filled discontinuity, spanning the entry at N 60° E, was located 8 ft north of the four-way intersection.

The test site was monitored 50 days after installation. The increased loading on the bearing plates, of 7,000 lb, in the four-way intersection was attributed to displacements associated with the clay-filled discontinuity. The vertical displacement gauges in the area recorded 0.2 to 1.0 in of total displacements. A visual observation of the roof area, with the aid of a fiber-optic stratascope, revealed a minor separation of 0.4 in at the 4-ft level. This separation occurred between layers of thinly laminated shale. Small amounts of loading, approximately 1,500 lb, developed near the three-way intersection. Only small amounts of displacement were recorded, with no apparent visual separations.

The instrumentation was read and evaluated at 87 and 128 days after installation. The loading pattern and roof displacements for the 128-day measurements are shown in figure 13. The highest degrees of loading were recorded in the vicinity of the discontinuity near the four-way intersection. Sloughing in the

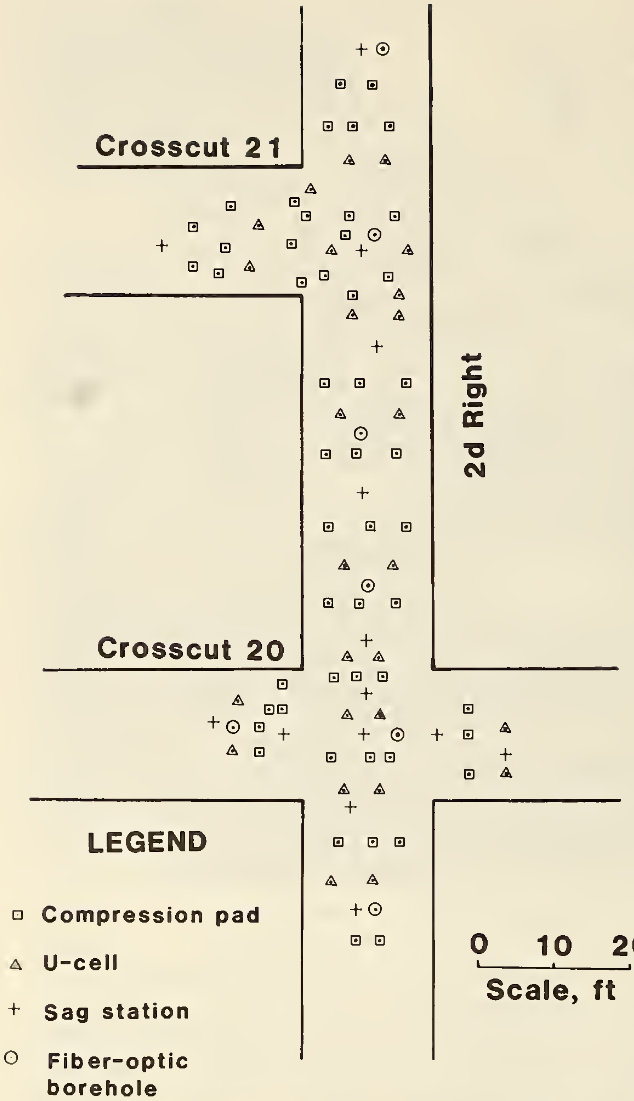

FIGURE 12.-Instrumentation layout in the Bear No. 3 Mine.

west ribs also contributed additional loads on the bearing plates. The average load on the bearing plates was approximately 5,400 lb. The displacements, measured at the 3-ft level, were as high as 1.8 in near the four-way intersection and 0.9 in in the middle of the three-way intersection. Twelve pressure pads were recording loads greater than 15,000 lb.

The loading patterns and roof movements recorded at 162 and 211 days were similar to those recorded at 128 days. The test site results indicated that loads on the bearing plates in the four-way intersection were increasing at a rate of approximately 100 lb per week. The displacements in the roof remained relatively consistent with the 128-day measurements. The corners of the pillars in the three-way intersection were visually inspected and observed to be beginning to yield, creating increased loading (fig. 13) in the immediate area. The condition of the roof appeared to be stable, even with an average of 5,900 lb of load being carried by the bearing plates.

Final instrumentation readings were acquired 311 days after the initial installation. The loading patterns and displacements are shown in figure 13. The test site underwent considerable changes in loading pattern that were attributed to the large degree of observed pillar yielding. The effective roof span, due to this pillar yielding, had increased by 16%, or 4 ft, causing an increase in the entry's centerline roof displacement. High loads were generated along the riblines in certain areas owing to the extended length of unsupported roof in the yield zone of the coal pillars. The minimum and maximum loads measured on the bearing plates were 600 lb and 26,700 lb, respectively. Theoretically, this maximum load would generate approximately 60,000 psi of pressure on a 3/4-in-diam bolt. This pressure exceeded the theoretical yield of the bolt system. The final calculated average load on the bearing plates was approximately 8,000 lb, an increase of 38% over previous readings.

The results from the test site in the Bear No. 3 Mine indicated, conclusively, that bearing plates are subjected to loading when installed in conjunction with full-column resin-grouted bolts. Roof movements and separations, monitored with vertical displacement gauges, corresponded closely with applied bearing plate loads. Instrumentation used in the two test sites has been shown, through past experience, to be both effective and reliable. Field data can be closely correlated to the stabilization of the entry.

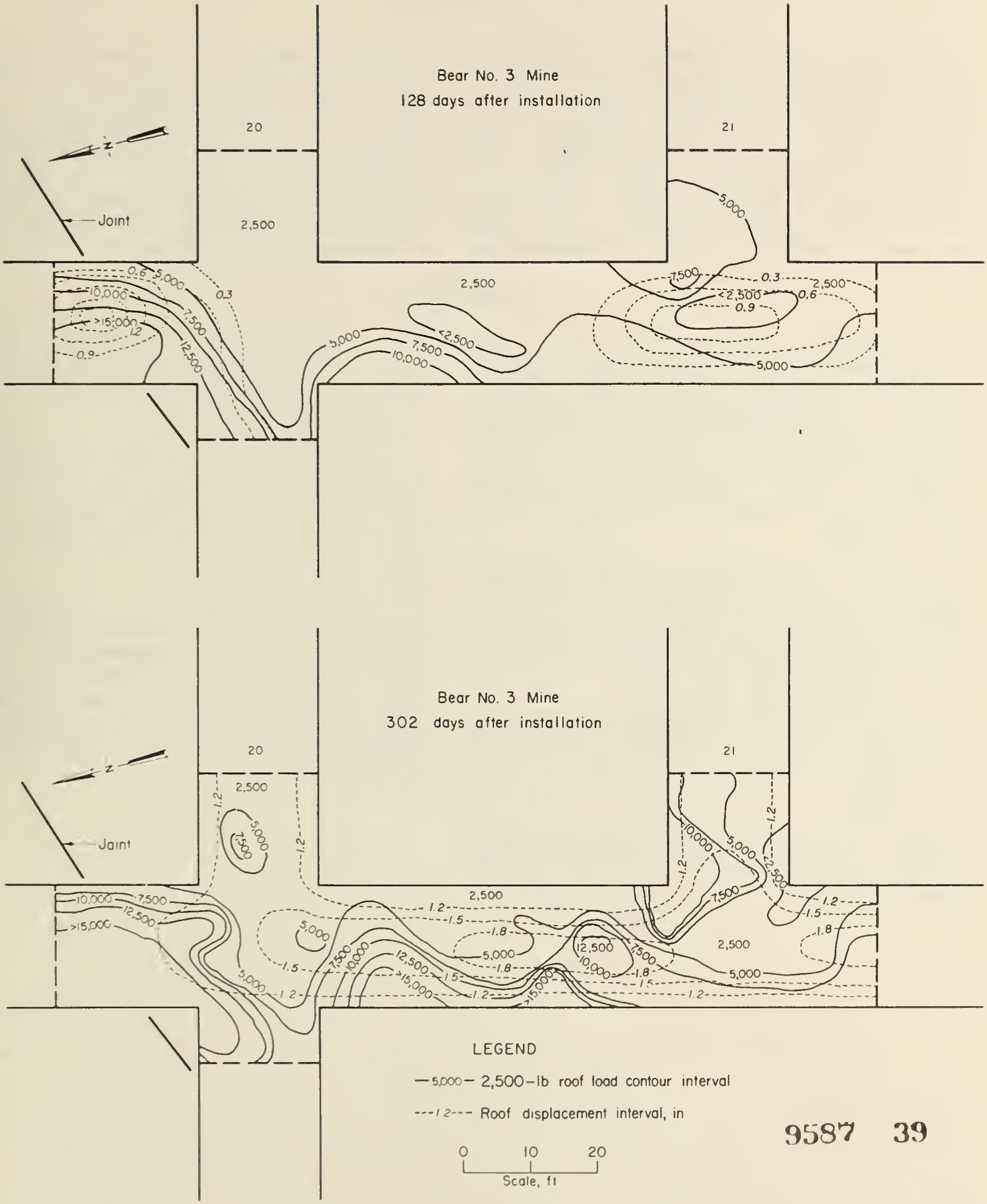

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FIGURE 13.-Bear No. 3 Mine load and roof displacement contours 128 days and 301 days after test site installation.

CONCLUSIONS

The field data of these two sites indicate that bearing plates at the heads of full-column, resin-grouted bolts can be subjected to significant loads. The bearing plates not only retain the roof material but support large amounts of generated load between bolts. The loads tend to be closely related to the roof movements owing to pillar yielding and geologic anomalies. In some instances, the loads on the plates were so extreme that the ultimate strength of the No. 6 rebar, grade 40 bolts was approached and exceeded. However, overall stability was maintained, as evidenced by the retention of constant loads measured on the bearing plates and negligible vertical displacement measurement increases.

REFERENCES

1. Coates, D. F., and Y. S. Yu. Three-Dimensional Stress Distributions Around a Cylindrical Hole and Anchor. Paper in Proceedings of the Second Congress of International Society for Rock Mechanics (Belgrade, Sept. 21-26, 1970). "Jaroslav Cerni" Institute for Development of Water Resources, Belgrade, 1970, pp. 175-181.

2. Haas, C. J., G. B. Clark, and R. N. Nitzsche. An Investigation of the Interaction of Rock and Types of Rock Bolts for Selected Loading Conditions (contract H0122110, Univ. MO). BuMines OFR 2-77, 1974, 342 pp; NTIS PB 267673.

3. Nitzsche, R. N., and C. J. Haas. Installation Induced Stresses for Grouted Roof Bolts. Int. J. Rock Mech. Min. Sci. and Geomech. Abstr., v. 13, No. 1, 1976, pp. 17-24.

4. Khalsa, N., and L. R. Ladwig (eds.). Colorado Coal Analyses 1976-1979. CO Geol. Surv., Inf. Ser. No.10, 1981, 246 pp.

5. Schwochaw, S. D. (comp.). Mineral Resources Survey of Mesa County--A Model Study. CO Geol. Surv., Resour. Ser. No. 2, 1978, pp. 35-38.

6. Osterwald, F. W., C. R. Dunrud, J. B. Bennetti, Jr., and J. O. Maberry. Instrumentation Studies of Earth Tremors Related to Geology and to Mining at the Somerset Coal Mine, Colorado. U.S. Geol. Surv. Prof. Paper 762, 1972, pp. 2-9.

7. American Society for Testing and Materials. Standard Specifications for Roof and Rock Bolt Accessories. F-432-77 in Annual Book of ASTM Standards: Part 10, Bolts, Threaded Bars, Threaded Slotted Bars, Bearing and Header Plates, and All Types of Washers. Philadelphia, PA, 1977, pp. 6-7.

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